SR Present Capabilities and Limitations

Low-emittance, other special lattices

Coupling, high brightness.

High-current running

Lifetime

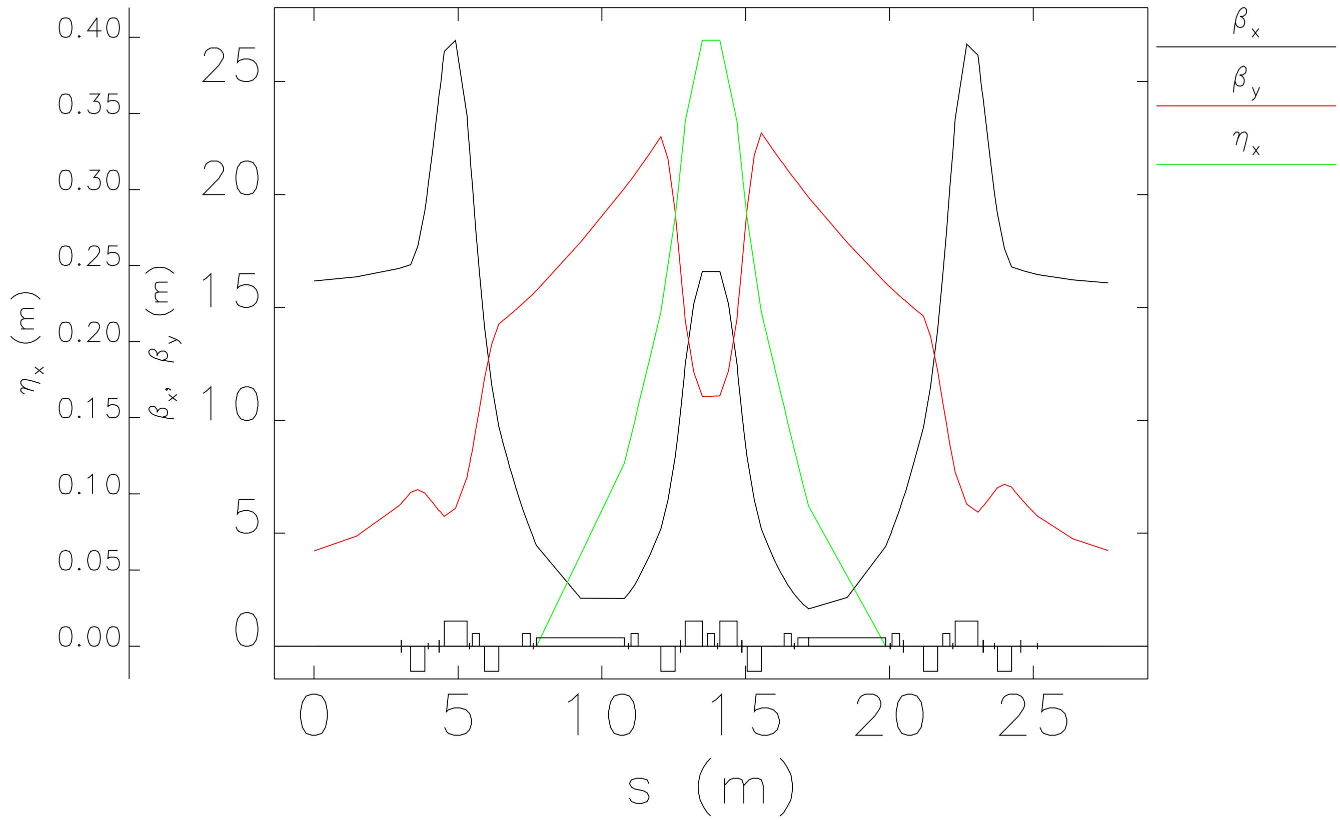
Chromaticity, sextupoles

Injection system

Small gap chambers

not covered: orbit stability

High-Emittance Lattice



High-Emittance Lattice (cont'd)

ε_x=7.5 nm-rad, minimized with η_x=0 m.

β_y minimized at ID for maximum acceptance.

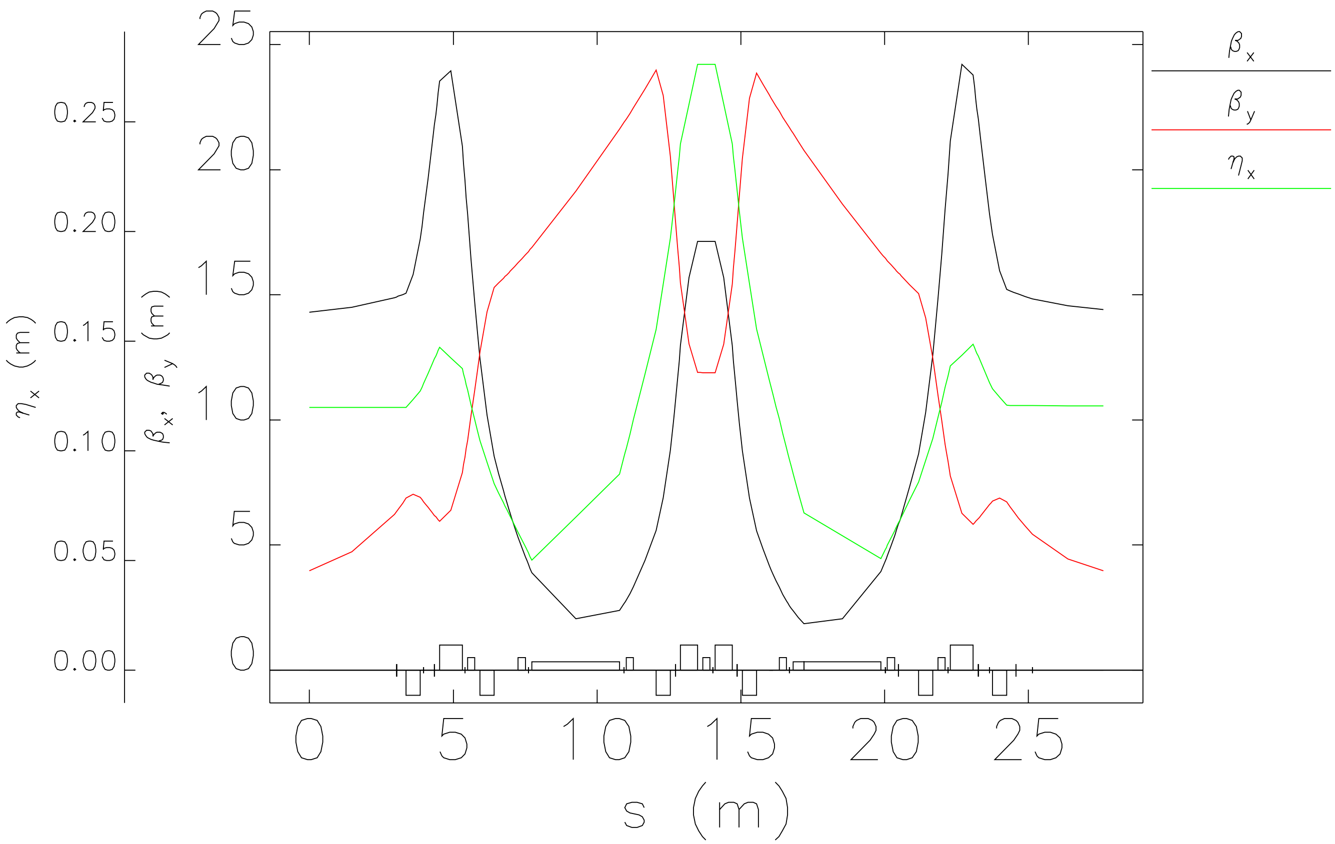
β_y in arcs constrained to reduce nonlinearities from strongest sextupoles.

ν_x=35.2, ν_y=19.27.

Sextupole families optimized.

- Chromaticity (S3 S4) set to allow 5 mA/bunch
- Harmonic (S1 S2) set to maximize momentum aperture (lifetime)

Low-Emittance Lattice



Low-Emittance Lattice (cont'd)

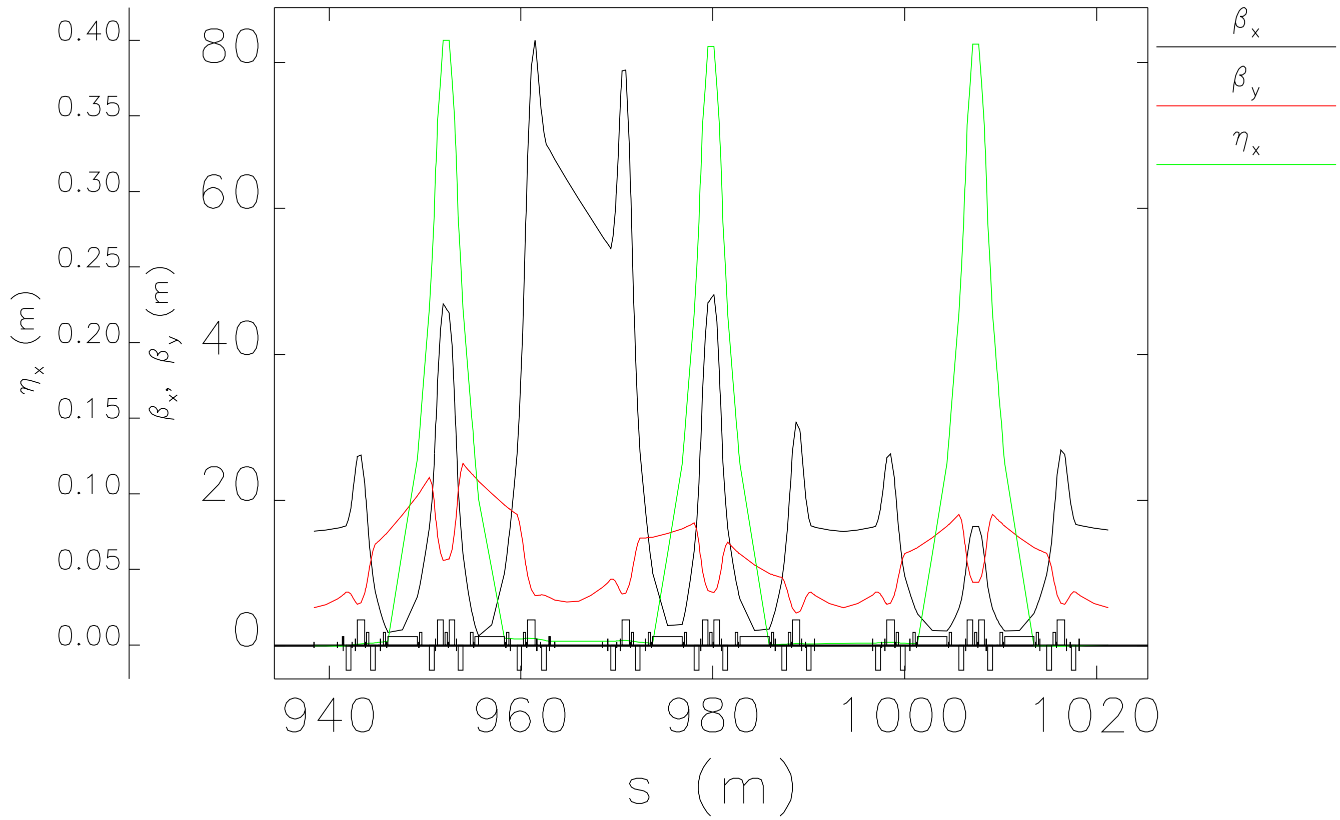
ε_x=3.3 nm-rad with η_x free.

Beamsizes at ID minimized: $\sigma_x^2 = \varepsilon_x \beta_x + (\sigma_\delta \eta_x)^2$

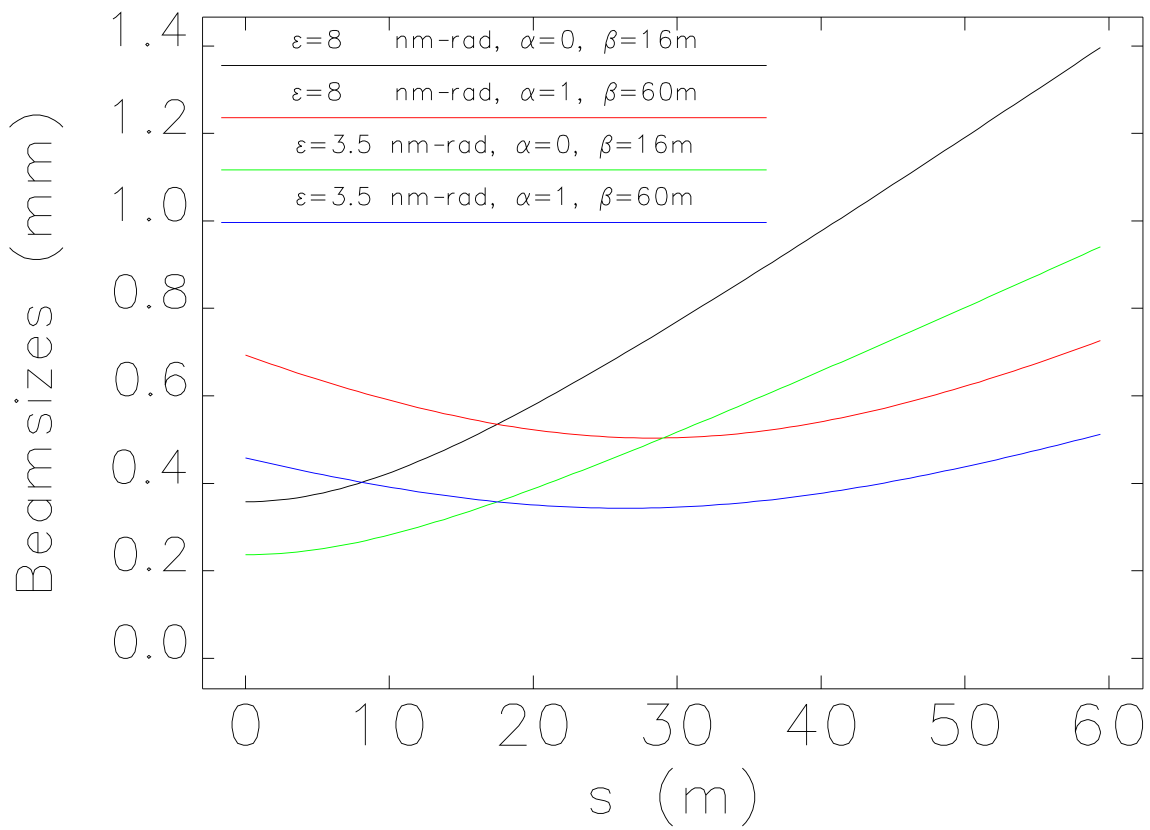
Sextupole families optimization.

- More complicated since all sextupoles have dispersion.
- "Chromaticity" (S3 S4) set to allow 5 mA/bunch. S3 maxed out.
- "Harmonic" (S1 S2) difficult to optimize.

Converging-Beta Lattice



Converging-Beta Lattice (cont'd)



Converging-Beta Lattice (cont'd)

Adapted to high-emittance lattice and characterized in machine studies.

Converging beta function increases the flux by focusing the photons to a point downstream in the beamline.

Limitation is high β_x in SS. Used β_x=60 m and α_x=1.

Sextupoles in 2 sectors are turned off.

- Need to increase other sextupoles.
- Unsymmetrical sextupole distribution around ring reduces dynamic and momentum aperture.
- Optimization of sextupole families for dynamic aperture or momentum aperture are incompatible in this case.

Lattice Perturbations

β function modulation reduces dynamic aperture and momentum aperture.

- Actual quadrupole gradient error appears to have small effect.
- Horizontal orbit steered through sextupoles larger effect: $\Delta(kl) = x_S(ml)$ is about 5% of dispersion matching focusing in worst case.
- ν_y=19.3 close to (0.5)(Ncells) = 20 amplifies the effect in y-plane.

Successful method to measure β everywhere quickly (1 hour) and calculate correction offline (1 hour) -> can correct other lattices.

- Perturbation in low-emittance lattice was corrected last run.
- Momentum aperture 1.5%-> 2.5%, which increased the lifetime by 40%.

Coupling

$\varepsilon_y/\varepsilon_x$ measured at 35 BM pinhole image reported as coupling.

High value of $\varepsilon_y/\varepsilon_x$ is usually good for lifetime, but can be bad for injection.

Strictly speaking, coupling is optics condition where motion of one plane is transferred to the other because of skew quadrupole fields $\bar{k}$ errors.

$\varepsilon_y = f(\bar{k}, \eta_y)$ where $\bar{k}$ terms transfers quantum excitation from x-plane to y-plane and η_y (=g($\bar{k}$)) terms generates Q.E in y-plane directly.

$\bar{k}$ is usually bad for injection (small gap VC aperture of 5 mm)

η_y doesn't affect injection as much.

Coupling Correction and Adjustment

Reduce effect of $\bar{k}$ and value of η_y using separate sets of skew quadrupole correctors (9 for η_y and 10 for effects of $\bar{k}$) and different methods.

Usually can reduce $\varepsilon_y/\varepsilon_x$ to 0.25% for maximum photon beam brightness with expected low lifetime.

Limitation of low coupling is the greater sensitivity to beam motion.

For higher lifetime and increase $\varepsilon_y/\varepsilon_x$ the “right” way, adjust η_y using 0th harmonic of 9 skew quadrupole correctors.

Lifetime

Gas scattering (single particle collision with gas nucleus/electrons) gives baseline of 170 h at 100 mA

- Average pressure is proportional to total current.
- Expect baseline of 85 h at 200 mA and 60 h at 300 mA

Touschek (2-particle internal collisions) scattering:

- p_x exchanged for p_z -> momentum aperture A_δ
- Particle density -> current per bunch I_b, bunch volume $V = \sigma_x\sigma_y\sigma_z$ through σ_y
- Nominal lifetime of 20 h for high-emittance lattice set by adjusting σ_y (coupling).

Bunch patterns

Any bunch pattern in 1296 buckets possible.

Limitation is charge per bunch through instability (single bunch) or RF heating (with many bunches).

Set chromaticity (ξ_x=4 ξ_y=6) for 5 mA single bunch stability limit.

Can achieve higher bunch current by reducing RF voltage (15 mA with 7.0 MV), but lifetime is much lower.

Standard patterns:

- 102 mA in 23 bunches (~4.5 mA/bunch)
- 15 mA in 3 bunches, 87 mA in 56 bunches. (1.8x lifetime as above)
- Requirement of sufficient charge and 300 ns spacing for bpm triggering.

High Chromaticity

Required for high single-bunch current.

$\Delta\nu_y = \xi_y\delta$ means that particles with large enough δ will have ν_y too close to n+1/2 resonance (n=19).

It appears that momentum aperture A_δ is controlled by ξ_y when ξ_y is high.

This is confirmed with observed lower lifetime when $\xi_y > 6$.

High-Current RF Operation

Four 1 MW stations available.

Normally use one station to power one pair of sectors (8 cavities).

Power requirements:

- No beam, 8.0 MV requires 500 kW, 9.5 MV requires 700 kW
- 100 mA requires 550 kW of additional power. (1300 kW)
- 200 mA requires 1100 kW of additional power. (1800 kW)
- 300 mA requires 1700 kW of additional power. (2400 kW)

Two stations (#1 and #4) have been combined to power one pair of sectors (38 and 40) for 200 mA store at 8.0 MV (machine study).

Kicker Chambers

Heating occurs from peak surface currents induced by beam: T ~ $\sum I_p^2$

Present and future chamber temperature are limited to 200 deg C.

ΔT for 5 mA/bunch and 102 mA is 80 deg. C.

Longer bunches reduces T, e.g. 8.0 MV RF operation for 200 mA.

Limitation of 5 mA/bunch operation at 200 mA.

Injector System

One bunch per cycle:

- Booster ramp limitation
- A second bunch 3 buckets away can be captured, but is not a easily-controlled condition.

3 nC/pulse allows low-lifetime (8 h) top-up operation.

Pulse magnet limitations:

- SR kickers waveform with a rounded top. 97% amplitude points are separated by 350 ns.

Injection Losses

Presently have 2 30 mm x 5 mm and 23 40 mm x 8 mm internal aperture chambers.

Injection losses cause demagnetization in ID.

Cause: nonlinearities and input trajectories.

With bad tuning, we may get 50% losses at first 5 mm chamber.

- Usually unobservable injection condition changes.
- Not easy to tune during User periods.

With good tuning, may get as a little as 1% loss (estimated) at the first chamber.

- Always achievable given enough study time.

Real-Time Radiation Detectors

Located at each ID and scraper.

Sufficiently sensitive to alert us to bad tuning in small-aperture VC.

Difficult to help make corrections unless the problem is an observable setting error.

ID VC impedance

ID VCs contribute most of the impedance that limit single bunch current.

β_y is already optimized, and must continue to be for future lattices.

With few chambers, current limit was about 20 mA at nominal RF setting.

Method in development to measure contribution of taper and resistance of wall.

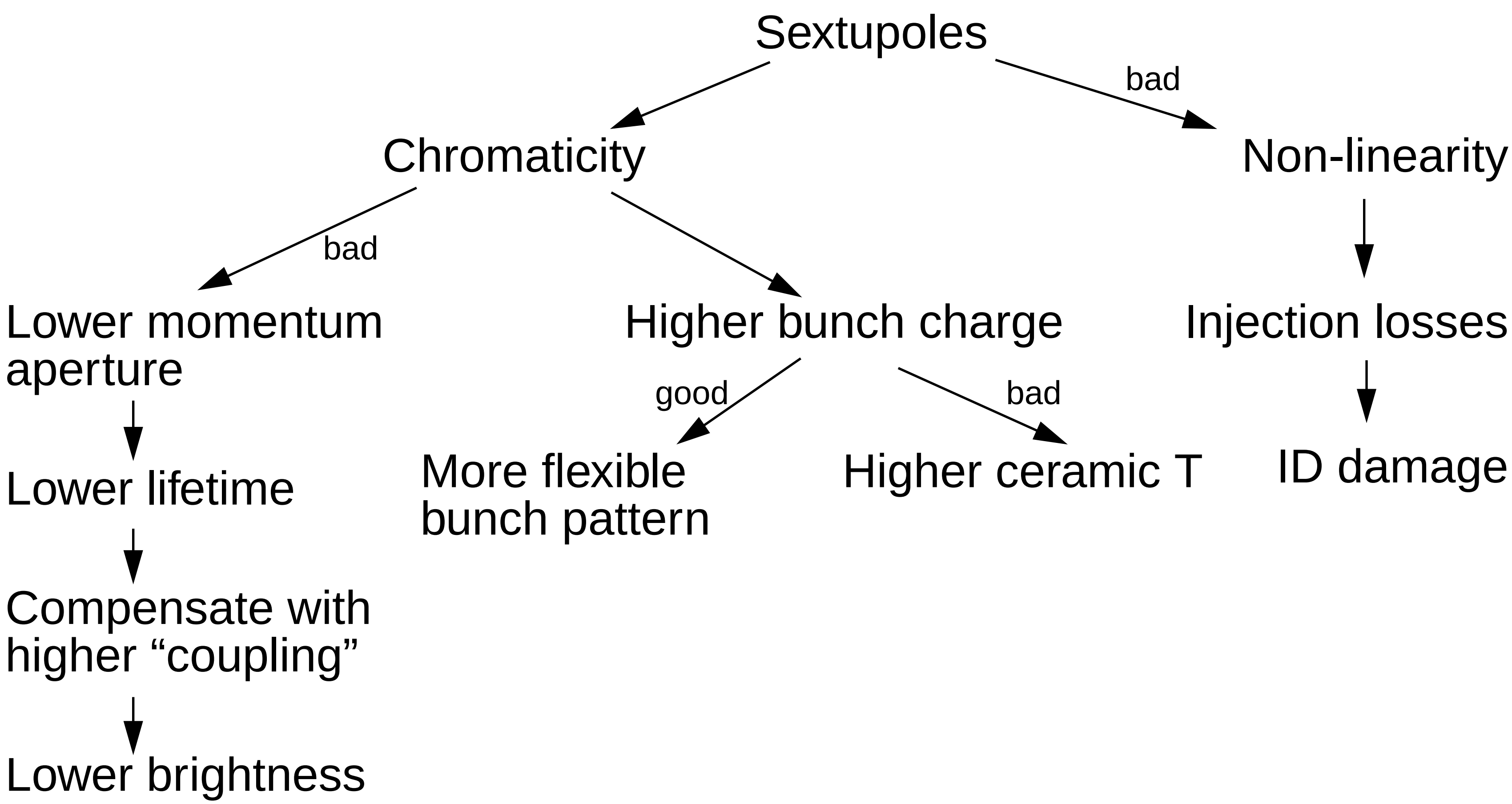
Sextupoles

Sextupoles are currently running at their maximum limit for low-emittance lattice since we changed from $\nu_y = 14.3$ to $\nu_y = 19.3$ for the 5 mm chamber.

Special lattices that require sectors of sextupole turned off will have much smaller single bunch limits.

Untested lattices with different integer tunes may have smaller sextupole requirements (about 20%) because of the slightly different β's.

Effect of Sextupoles



Matrix of problems

Upgrades	Low lifetime	Low charge per bunch	Low injection efficiency	High ceramic T
Split cells in 2	X		X	
Damping partition	X		X	
Increase Current	X	X		X
Converging beta	X		X	
Increase sextupole	X			

Upgrades	Low lifetime	Low charge per bunch	Low injection efficiency	High ceramic T
Add more 5 mm ID VC	X	X		
Fast feedback				